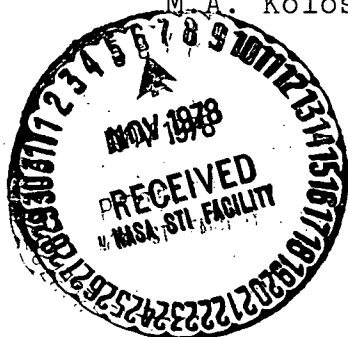


RADIOPHYSICAL INVESTIGATIONS OF VENUS FROM SPACECRAFT

M. A. Kolosov and O. I. Yakovlev



Translation of "Radiophisicheskiye issledovaniya Venery c
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16. Abstract The atmosphere and topography of Venus were studied in detail from the Venera-9 and Venera-10. Research on plasma around the Sun was also carried out. Information on pressure, temperature and gas composition of the atmosphere in five regions of the planet was obtained. The Venera-9 and Venera-10 transmitted useful information for several months, making a detailed study possible. Radio waves and fluoroscopy were used as the research methods.			
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RADIOPHYSICAL INVESTIGATIONS OF VENUS FROM SPACECRAFT

M.A. Kolosov, Professor and
O.I. Yakovlev, Doctor of Technical Sciences

Soviet radiophysicists, using the automatic interplanetary stations, the Venera-9 and the Venera-10 have studied the atmosphere and topography of Venus in detail and have conducted research on plasma around the Sun.

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The New Stage of Research

Direct study of Venus using spacecraft was begun by the Soviet interplanetary stations, the Venera-4, -5, -6, -7 and -8. The descent craft of these stations brought information from the depths of the deep atmosphere of Venus as to pressure, temperature and the gas composition of the atmosphere in five regions of the planet (Zemlya i Vselennaya, No. 5, 1974, pp. 42-46, Editor). The advantage of remote control methods is that they permit studying the properties of the atmosphere and the surface of a planet on a planetary scale. Remote methods are also the only possible methods when it is impossible to man a spacecraft in an area of interest to us, for example, in the space around the Sun.

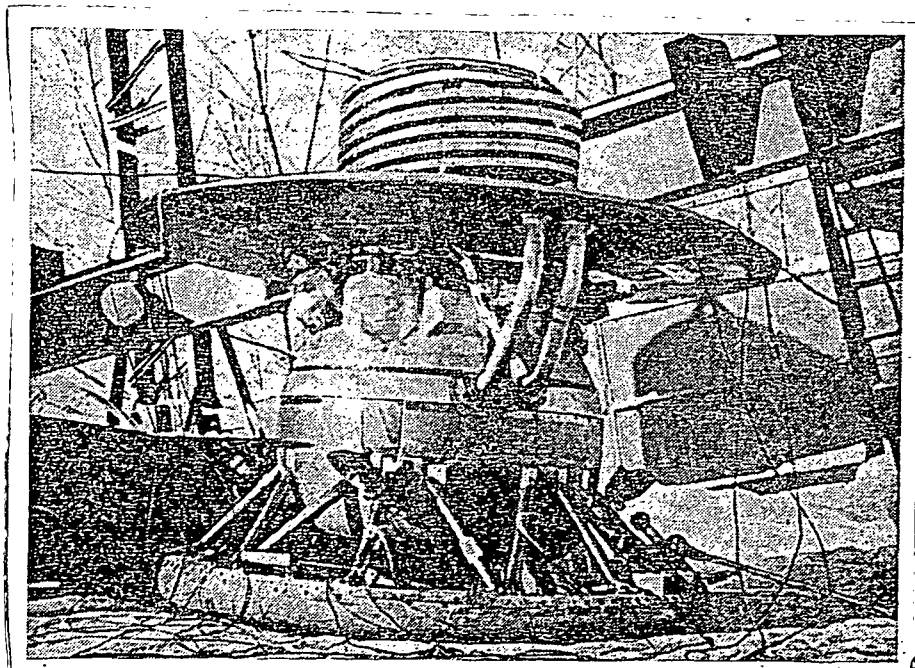
Launching of the first Venus satellite in the world, the Venera-9 and Venera-10 expanded the possibilities for studying the planet. These were long lasting spacecraft carrying out the space watch for many months. The long term operation of a large set of instruments mounted on stations made it possible to study Venus in detail.

The artificial satellites of Venus conducted three complex radiophysical experiments whose basis was the effect of the

*Numbers in the margin indicate pagination in the foreign text.

atmosphere on the parameters of radio waves. The characteristics of the radio waves (amplitude, frequency, etc.) just like the characteristics of light waves, are found to be in direct relationship to what medium these wave encounter on their paths, a polished surface or a rough one, a nonprocessed, mirror or transparent glass, or an "absolute black body."

The upper part of the atmosphere of Venus was studied by a method of fluoroscopy at an altitude intervals from 40 to 500 km over the surface of the planet. A method of reflecting radio waves from the surface of the planet brought new information as to the topography and change in pressure on the surface depending on the topography. With fluoroscopy of the plasma around the Sun, the rate of efflux of plasma from the Sun was successfully measured and the characteristics of turbulence of the near Sun plasma was determined.



Analog of a descent vehicle of interplanetary automatic Venera-9 and Venera-10 stations on a test stand. TASS Photoservice.

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Atmosphere

Studies were begun in October, 1975, immediately after the Venera-9 and Venera-10 became artificial satellites of Venus. Before entry of the station behind the planet, the radio waves were propagated through its atmosphere on the nocturnal side of Venus and after exit from behind the planet, fluoroscopy of the diurnal atmosphere of Venus was carried out. It is very important that the fluoroscopy was successfully accomplished at different regions of the planet, in the equatorial, and polar regions and in the middle latitudes. The ionosphere and troposphere were studied with fluoroscopy. Radio beams passing through the troposphere cannot penetrate deeper than 35 km over the surface of the planet. Therefore, the fluoroscopy method gives information on the atmosphere in an altitude range from 40 to 500 km. /34

The dense atmosphere of Venus has a strong effect on the characteristics of radio waves passing through it. Frequency and amplitude of radio waves which are accurately recorded at the Center for Outer Space Radio Communication are changed and serve as the basis for determining the parameters of the atmosphere. Variations in amplitude and frequency of radio waves during exit of the satellite from behind the side of the planet illuminated by the Sun made it possible to establish the distribution of pressure and temperature according to altitude, to evaluate turbulence of the atmosphere and to study the ionosphere of the planet. Pressure at an altitude of 40 km was equal to 3.5 atmospheres and at an altitude of 51 km over the surface of the planet, 1 atmosphere. The gas shell of Venus is thicker than that of Earth. At an altitude of 86 km from it the pressure amounts to a thousandth part of the atmosphere and on Earth, such a pressure corresponds to an altitude of 48.6 km.

The temperature on the diurnal and nocturnal sides of the planet at different altitudes are distributed in the following

way: at an altitude of 51 km, corresponding to the level of pressure on the surface of the Earth, the temperature equals 74°C . With a decrease in altitude, the temperature increases by 9.8°C for each kilometer. It is significant that the lower part of the atmosphere has a constant thermal state, at altitudes less than 55 km the temperature on the diurnal and nocturnal sides are practically identical. Above 60 km, one observes a significant divergence between the temperature of the diurnal and nocturnal sides of the planet. At an altitude of 70 km, the temperature in the daytime is $15\text{--}20^{\circ}\text{C}$ higher than at night.

The characteristics of distribution of temperature make it possible to understand the mechanism of wind formation in the atmosphere of Venus. In the lower dense atmosphere which has a constant temperature, a slow migration of gas must occur. And actually, measurements using descent vehicles indicated that wind velocity at low altitudes is very small. At an altitude of about 65 km, where there is a difference between temperature on the diurnal and nocturnal sides of the planet, strong winds must "blow" and they cause strong turbulence in the atmosphere. The turbulence of the atmosphere, in turn, results in the appearance of rapid fading of the signal. Actually, an analysis of the fading of signals during fluoroscopy of the atmosphere confirms the fact that at altitudes of 56--68 km, one observes an increase in turbulence.

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The atmosphere at altitudes above 95 km is ionized. On the diurnal side of the planet, the concentration of electrons depends strongly on the zenith angle of the Sun. In the daytime, with a zenith angle of the Sun $14\text{--}16^{\circ}$, the ionosphere atmosphere is located at an altitude of 140 km, the electron concentration equals $(4\text{--}4.5) \cdot 10^5\text{ cm}^{-3}$. With large zenith angles of electrons, it becomes smaller: for zenith angles of the Sun 75 and 83° , the electron concentration at a maximum,

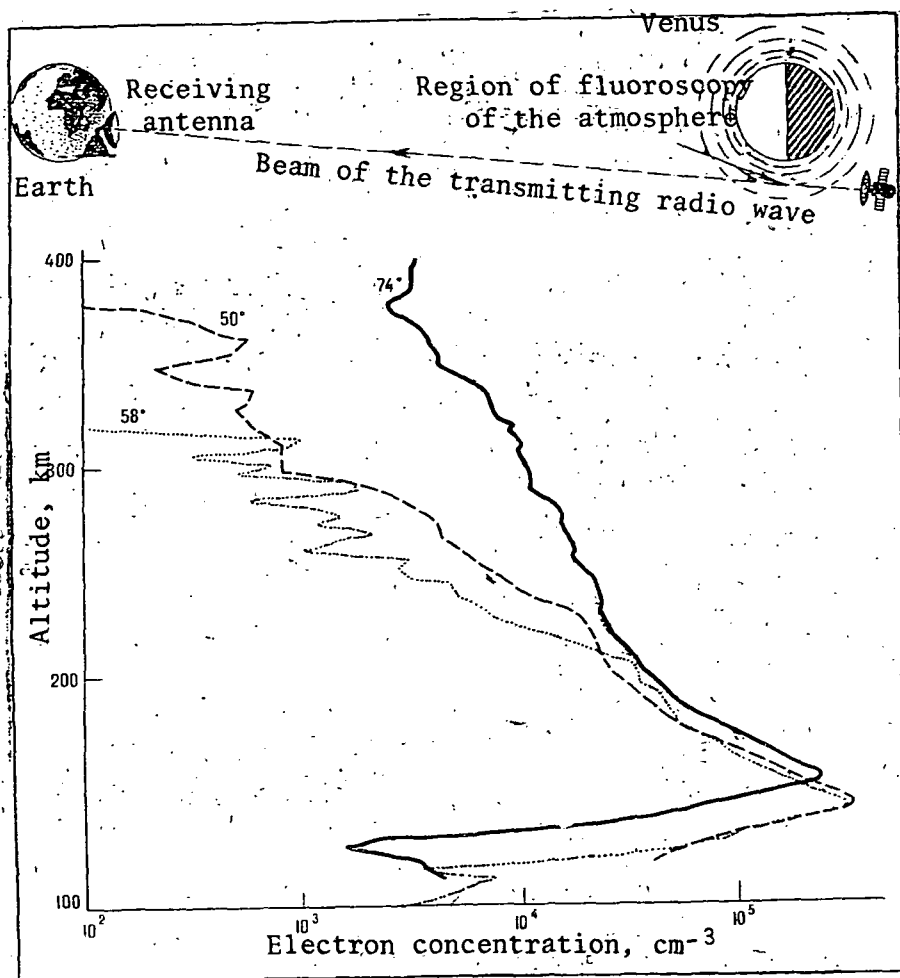
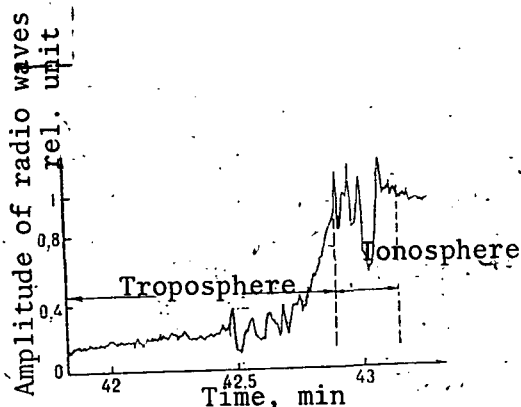
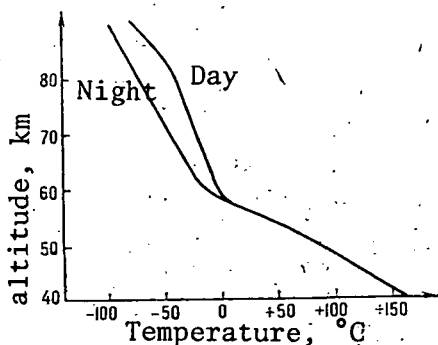


Diagram of fluoroscopy of the atmosphere of Venus. Electron concentration of the diurnal ionosphere of Venus under different conditions of illumination of the planet by the Sun. The figures on the curves are at the zenith angle of the Sun (in degrees).



Change in amplitude of radio waves under the effect of the troposphere and ionosphere.



How the temperature of the diurnal and nocturnal sides of Venus change depending on altitude over the surface of the planet.

Topography

An outstanding achievement of space technology is the first photographs of the surface of Venus received by the descent vehicle of the Venera-9 and Venera-10 stations (Zemlya i Vselennaya, No. 3, 1976, pp. 3--15. Editor).

The first information on the topography of Venus discovered

respectively, equals $2.5 \cdot 10^5$ and $1.8 \cdot 10^5 \text{ cm}^{-3}$. The ionosphere of Venus extends to altitudes of 400--600 km. At this same altitude, a sharp decrease occurs in the concentration of electrons which causes "sweeping out" of the gas from the highest section of the ionosphere by the inflowing flux of interplanetary plasma. This plasma flux is caused by the effect of the Sun which generates a singular phenomenon, solar wind (Zemlya i Vselennaya, No. 5 1968, pp. 2--7, Editor).

The nocturnal ionosphere of Venus has an electron concentration ten times smaller than the diurnal. The diurnal ionosphere of Venus has an electron concentration approximately three times smaller than the diurnal ionosphere of Earth and occupies three to four times less space according to altitude than does the ionosphere of Earth.

under the dense cloud covering was obtained by radar from Earth. This was possible thanks to the precise measurements of the distances to certain sections of the surface of the planet (Zemlya i Vselennaya, No. 1, 1977, pp. 24--27. Editor). Studies made in the USSR under the direction of academician V.A. Kotel'nikov indicated that the surface of the planet had a complex topography.

The Venera-9 and Venera-10 stations studied the topography close to the visible limb of the planet. These regions are difficult to study with radar from Earth and therefore the topography was determined by a method of reflecting radio waves emitted by the stations. On command from Earth, the spacecraft turned so that the directional antenna bombarded the surface of the planet with radio waves. The reflected radio waves are received on Earth and according to their characteristics detect the peculiarities of the topography. The parameters of the reflected radio waves make it possible to determine, inasmuch as one or another region is higher or lower than the spherical surface, what kind of topography this region has. The coordinates of the regions studied on the surface of Venus are determined according to the trajectory of the spacecraft. An analysis of the degree of irregularity of the topography indicated that in the plain region, the topography is very smooth and reminds one of lunar seas. Irregular relief is characteristic for these same regions where one observes a change in altitude along the route studied.

The totality of radio physical measurement and direct photography made it possible to study the relief of the planet best. It was found that on Venus, there are broad plains with extremely smooth relief and mountain formations.

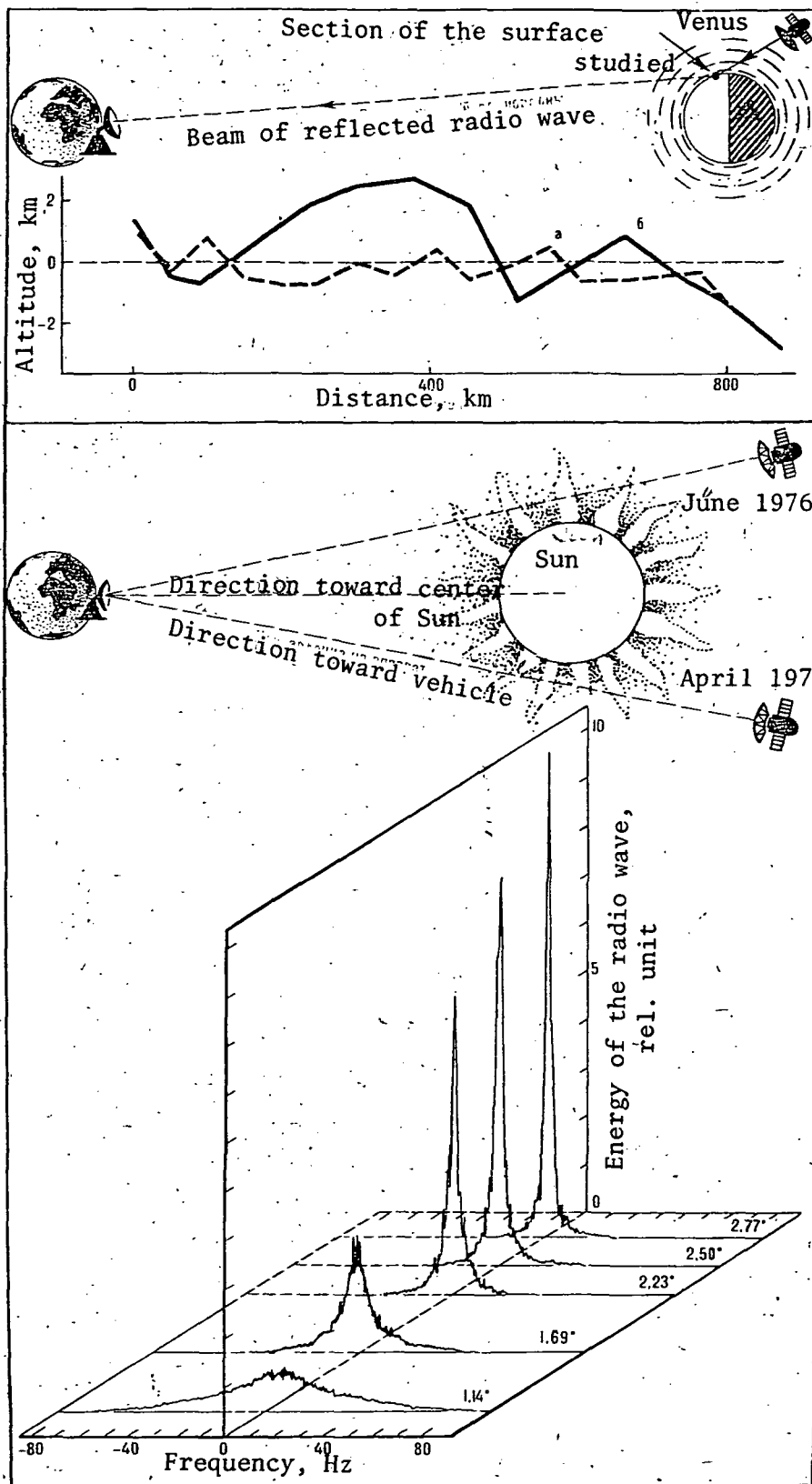


Diagram of reflection of radio waves from the surface of Venus.

The relief of two regions of Venus extending for about 800 km. The first region (a) is smooth, the second (b) is characterized by irregularities reaching 2 kilometers in altitude.

Diagram of radio-sonde observations of near Sun plasma.

Expansion of the spectra of radio waves as the radio beam approaches the Sun.

Near Sun Plasma

After completing experiments of fluoroscopy of the atmosphere and studying the topography of Venus, a study was begun of plasma around the Sun. In this experiment, the length of the radio communication path amounted to 250--260 million kilometers. The radio beam travelled the Venus-Earth route through near Sun plasma at different distances from the center of the Sun. In April, 1976, when the studies had begun, the angle between the center of the Sun and the vehicle was equal to 15° , and the radio beam passed from the center of the Sun at a distance of 40 million km. Because of the movement of the planets, this angle is decreased and on June 16, 1976 it amounted to a total of 0.6° . The radio beam, at this time, passed at a distance of 0.9 million km from the center of the Sun. Then, the vehicle went behind the Sun and in July of the same year, a probe was made of the near Sun plasma at an increased distance from the path of radio communications to the Sun. /37

It is well known that solar winds cause many phenomena on Earth and on other planets. Therefore, it is very important to know its characteristics. Transmitters of the Venera-9 and Venera-10 stations emitted highly stable sinusoidal oscillations with a frequency of 928 MHz. The effect of irregularities of the plasma absorbed by solar wind on the radio waves caused chaotic oscillations in the frequency and amplitude. These variations resulted in an expanded band of the energy spectrum of the radio waves. Analysis of recorded phenomena made it possible to determine the velocity of solar wind and the degree of turbulence of the plasma. It was apparent that the velocity of the solar wind increases with an increase in distance from the center of the Sun. At a distance of 1.6 million km, it equals 35 km/s, at 10 million km, 150 km/s. Turbulence of the same plasma, on the other hand, rapidly decreases with an increase in the distance to the center of the Sun. At distances of more than 5 million km, the turbulence of the plasma is stabilized and in a region of 9--12 million km, it even increases.

Simultaneous measurement of the velocity of solar wind and the degree of turbulence of the plasma makes it possible to understand better the mechanism of formation of solar wind. A decrease in the degree of turbulence of the plasma with an increase in distance to the center of the Sun must be accompanied by heating of the plasma because energy of motion of vortices is transferred to thermal motion of atoms. Strong turbulent heating of the plasma causes its expansion. Therefore, the velocity of solar wind increases particularly in this region where nonuniformity of the plasma subsides.

The first artificial satellites of Venus produced broad information on the planet. We have discussed only the radio-physical part of these studies.